Secondary Breakdown in Transistors

At high currents, reverse biased semiconductor diodes and transistor collector-base junctions operating under normal impact ionization breakdown conditions change to a low sustaining voltage mode of operation [1]. This secondary breakdown starts when the temperature in the junction locally reaches a critical value [2]. Then an intrinsic conducting region or a molten zone is established through the space charge region [3, 4]. These high conducting regions act as a short circuit to the current, so that the secondary breakdown sustaining voltage is caused by the voltage drop across the spreading resistances to these regions [4]. Most of the diodes and transistors show irreversible deteriorations of their current-voltage characteristics if large numbers of secondary breakdown pulses are applied, especially in circuits, in which no emitter current is allowed to flow. With rising current, the avalanche breakdown region in the base-to-emitter short circuited connection passes over, through the area modulation [2] or pinch-in region [5], [6], to approximately the same avalanche breakdown characteristic as in the open base connection. For different circuit connections, secondary breakdown starts at the same avalanche breakdown current. At the onset of the secondary breakdown, a voltage transition to the intrinsic conducting behavior with a time constant of a few μsec is observed. If the applied pulse power is high, this intrinsic conducting secondary breakdown region is crossed over within a short time and secondary breakdown with a molten zone sets in. The voltage jump at the onset of the secondary breakdown melting zone often causes relaxation oscillations. The junction space-charge ca-

Manuscript received November 12, 1963; revised manuscript received November 26, 1963.

TABLE I

Type of Transistor	Collector-Base Breakdown Voltage	Collector Space-Charge Layer Doping Density	Secondary Breakdown Starting Temperature	
			$T_{(n_i=N)}$	T_B Experimental
MM 1613 Si *n-p-n*	107 v	$N_D=2\cdot10^{15}$cm^{-3}	540°K (270°C)	532°K–565°K (259°C–292°C)
2N 1523 Ge *p-n-p* (After [2])	103 v	$N_A=4{,}2\cdot10^{16}$cm^{-3}	435°K (162°C)	438°K–491°K (165°C–218°C)
Si *p-n* diode (After [3])	>500 v	$N\cong5\cdot10^{14}$cm^{-3}	500°K (223°C)	473°K (200°C)

pacitance and the circuit capacitance then discharge through the molten zone of the secondary breakdown region. After the discharge of the capacitance, the breakdown channel stays in a high conducting state for 1 to 2 μsec. In this time the breakdown region cools down sufficiently to cause solidification of the molten zone. The conductivity then drops to the lower conducting state. Thereupon the capacitance is charged again through the source resistance. Under appropriate circuit conditions discharge current pulses as large as 10 amperes with a duration of 10 to 20 m/μsec can be obtained without destruction of the transistor (2 N 2218).

For the initiation of the intrinsic conducting secondary breakdown a more detailed model is presented. The collector current flowing through the high electric field of the collector-base region heats up this junction. In one spot the lattice temperature reaches a value at which the thermally generated carrier density (intrinsic density n_i) becomes as large as the donor or acceptor densities of the respective parts of the space charge region. From the highest field zone of the junction these thermally generated carriers move in such directions that the space charge density originating from the ionized donors and acceptors is partly compensated. The electric field and the voltage drop over this region both diminish. An intrinsic conducting region forms, concentrating most of the current through the junction. The conductance of this channel grows exponentially with temperature and jumps to a much higher value (with Si; 30 times, with Ge; 15 times) as the melting point of the material (Si: 1420°C, Ge: 940°C) is reached [4].

Experimental evidence for the start oJ the secondary breakdown at a temperature T, at which $n_i=N_D$, can be given as follows. From the avalanche breakdown voltage BV_{CBO} of the collector-base junction with open emitter one obtains the approximate value of the doping concentration N at the higher resistance side (collector) of the junction, using experimental relationships between doping density and breakdown voltage for such junctions. The temperature $T(n_i=N)$, at which the intrinsic concentration n_i equals the doping concentration N, can then be evaluated. This temperature is compared in Table I with the runaway temperature T_B of the secondary breakdown as determined experimentally using a method given by Ford [2]. The time τ, which a pulse with a given power $P=I_C\cdot V_{CEO}$ needs to trigger the secondary breakdown, is measured for different collector junction and ambient temperatures (transistor in oil bath) (Fig. 1). For the same secondary breakdown trigger time τ, the breakdown spot tempera-

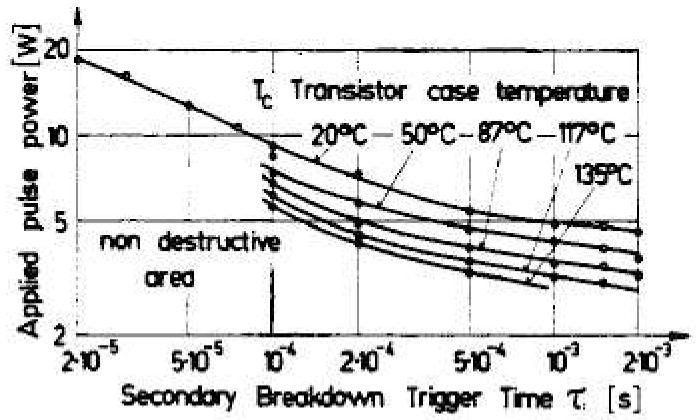

Fig. 1—Time τ, a pulse with a power $P=I_C\cdot V_{CEO}$ needs to initiate the secondary breakdown at different transistor case temperatures T_C for a silicon transistor MM 1613 in the open base connection.

ture T_B is approximately related to the pulse powers $P=I_C\cdot V_{CEO}$ at different case temperatures T_C by the thermal relation $T_B=T_C+K\cdot P$, where K is a constant. These relationships, if established at different case temperatures T_C, allow the secondary breakdown temperature T_B to be determined experimentally. In Table I it is shown that for these transistor types the experimental secondary breakdown trigger temperatures correspond to the temperature at which $n_i=N$. Hence we may conclude that such junctions with low breakdown voltage have a high secondary breakdown trigger temperature and junctions with high breakdown voltage have a low secondary breakdown trigger temperature.

The power-time relations as plotted in Fig. 1 for different case temperatures are useful to determine how long a given pulse-power may be applied to the transistor without causing a secondary breakdown.

H. Melchior
M. J. O. Strutt
Dept. of Advanced Elec. Engrg.
Swiss Feder. Institute of Technology
Zurich, Switzerland

References

[1] C. G. Thornton and C. D. Simmons, "A new high current mode of transistor operation," IRE Trans. on Electron Devices, vol. ED-5, pp. 6–10; January, 1958.
[2] G. M. Ford, "Collector to emitter breakdown related to thermal runaway in homogeneous base germanium power transistors," *Solid State Design*, vol. 4, pp. 29–36; June, 1963.
[3] H. Oka and S. Oshima, "Breakdown in Silicon Power Diode," Mitsubishi Denki Lab., Amagasaki, Japan, Repts. No. 3, pp. 165–181; 1962.
[4] A. C. English and H. M. Power, "Mesoplasma breakdown in silicon junctions," Proc. IEEE (*Correspondence*), vol. 51, pp. 500–501; March, 1963. A. C. English, "Mesoplasmas and second breakdown in silicon junctions," *Solid State Electronics*, vol. 6, pp. 511–521; September-October, 1963.
[5] F. Weitzsch: "Zum Einschnüreffekt in Transistoren, die im Durchbruchsgebiet betrieben werden," *Arch. elekt. Uebertragung*, vol. 16, pp. 1–18; January, 1962.
[6] F. Bergmann and D. Gerstner, "Thermisch bedingte Stromeinschnürung bei Hochfrequenz-Leistungstransistoren," (Ein Beitrag zum Problem des "Second Breakdown"), *Arch. elekt. Uebertragung*, vol. 17, pp. 467–475; October, 1963.